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Pacific Northwest Region

EVALUATION OF TIMBER VOLUME LOSS
DUE TO ARMILLARIA ROOT ROT
AND
SUGGESTED MANAGEMENT ALTERNATIVES
TO MINIMIZE FUTURE LOSS
ON THE
KLAMATH RANGER DISTRICT
WINEMA NATIONAL FOREST, OREGON

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EVALUATION OF TIMBER VOLUME LOSS DUE TO ARMILLARIA ROOT ROT AND SUGGESTED MANAGEMENT ALTERNATIVES TO MINIMIZE FUTURE LOSS ON THE KLAMATH RANGER DISTRICT, WINEMA NATIONAL FOREST, OREGON

by

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ABSTRACT

Survey of Armillaria root rot in a 230 ha (574 ac) mixed conifer forest in southern Oregon revealed that an average of 7 percent of the stems per unit area are infected, representing 32 percent of the cubic wood volume (145 m^3/ha., 2,074 $ft.^3$/acre) and 34 percent of the board-foot volume (9,413 bd. ft./acre). More than half of the infected timber has been killed by the disease. Infection and mortality, characterized by several large disease centers (1 to 4 ha, 2.5 to 10 ac), has been occurring primarily in the larger diameter trees over the past 40 years. Practical control measures and disease management alternatives for infected areas are discussed.

INTRODUCTION

Root rots cause an estimated growth loss of 62 million and mortality of 53 million cubic feet annually in the forests of Oregon and Washington (Childs and Shea, 1967). Armillaria root rot, caused by the fungus *Armillariella mellea* (Vahl ex Fr.) Karst., causes a substantial portion of this loss, especially in the mixed fir and pine forests east of the Cascade Range. In a survey of plantation diseases, Armillaria root rot was the most common and widely distributed root disease in Oregon and Washington (Johnson, 1976). Practically all commercial tree species are susceptible to Armillaria root rot (Raabe, 1962).

Armillariella mellea persists in infected root systems of both living and dead trees. The fungus spreads underground primarily by infective structures known as rhizomorphs which grow from the roots of infected trees to roots of adjacent healthy trees (Rishbeth, 1972). Tree-to-tree spread by root contacts and grafts is also common. Infection and spread

by fungus spores is considered rare. Disease centers develop when several adjacent trees are killed over a period of time. The origin of disease centers, at least in certain ponderosa pine *(Pinus ponderosa*, Laws) stands investigated in southern Washington, is associated with harvesting of healthy appearing but Armillaria-infected old-growth trees (Shaw et al., 1976). These disease centers characteristically developed around old-growth pine stumps (Figure 1).

Infections of *A. mellea* can remain dormant for years on lateral and lower taproots of living trees without visible above-ground symptoms, especially in large diameter trees. Under certain undetermined conditions, harvesting of such trees can result in infection and mortality of many surrounding understory trees. The shift from fungal parasitism on living trees to saphrophytism on dead (harvested) trees is believed to cause an increase in energy for infection (inoculum potential), especially in trees of large size (Roth, personal communication). Under proper conditions, understory trees in contact with or adjacent to infected old-growth stumps become infected, and over time the pathogen spreads from tree-to-tree via root and/or rhizomorph contact.

Inoculum potential is associated with several other factors. The larger the infected stump, the greater is the inoculum potential for infection of adjacent trees, since large stumps contain more nutrients for fungus growth than do small stumps. Other factors such as tree species involved; number and position of infected stumps in relation to adjacent trees; degree of stump decay; and soil type, moisture content, temperature, and pH all may affect inoculum potential on a particular forest site. Specific data for these variables are still unknown and would be highly desirable to predict future epidemics.

Armillaria root rot is generally considered a disease afflicting weakened or suppressed trees, as is the case in most forests west of the Cascade Range. Disease centers created by *A. mellea* have been discovered in vigorously growing stands, particularly on eastern slopes of the Cascade Range. In predominantly young-growth ponderosa pine stands of high site class in southern Washington mortality of $24 m^3/ha$ (340 $ft.^3/acre$), characterized by several large disease centers, has occurred over a 14-year period due to Armillaria root rot (Shaw et al., 1976).

Other areas severely affected by Armillaria root rot exist in the Pacific Northwest. This report describes an evaluation of forest land infected by Armillaria root rot in an epidemic state. The objective of the evaluation was to determine the extent of Armillaria and other root diseases in the area and measure associated timber volume loss. These data would then be used to formulate recommendations for forest practice. The area is also of considerable interest because it possibly represents, per unit land area, one of the most destructive examples of Armillaria root rot in the Pacific Northwest.

EVALUATION METHODS

Area Description

The evaluation was conducted in southern Oregon on the Klamath Ranger District, Winema National Forest (T. 32 S., R. 6 E., secs. 15, 22, 23, and 27) near the southern boundary of Crater Lake National Park (Figure 2). The stand surveyed

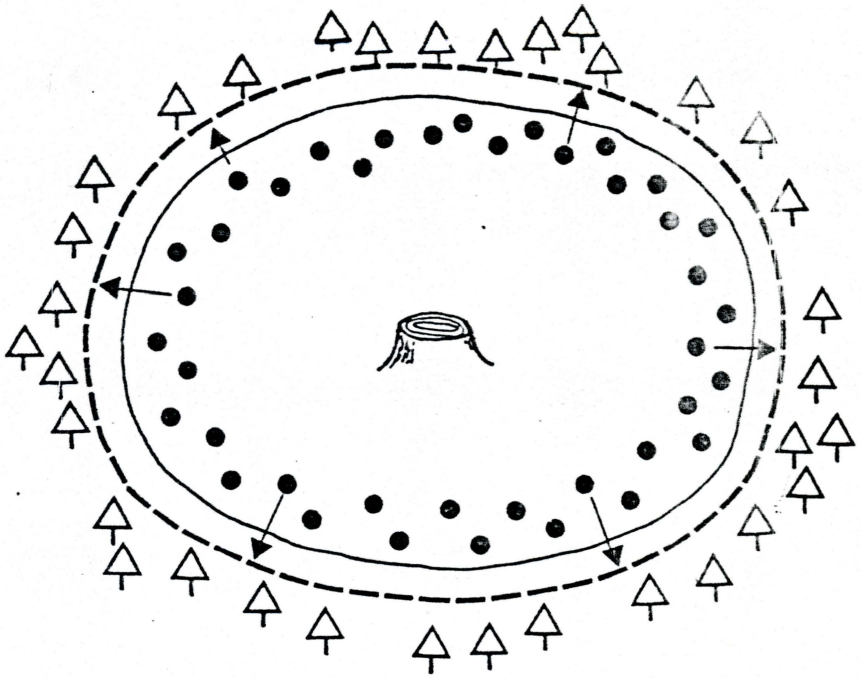
Infected old-growth pine stump
Infected young-growth pine stubs and snags
Limit of obviously infected trees
Limit of trees with hidden infections
Healthy trees
Direction of spread by A. mellea

Figure 1.--Highly schematic diagram of a disease center caused by *Armillariella mellea* in a young ponderosa pine forest.

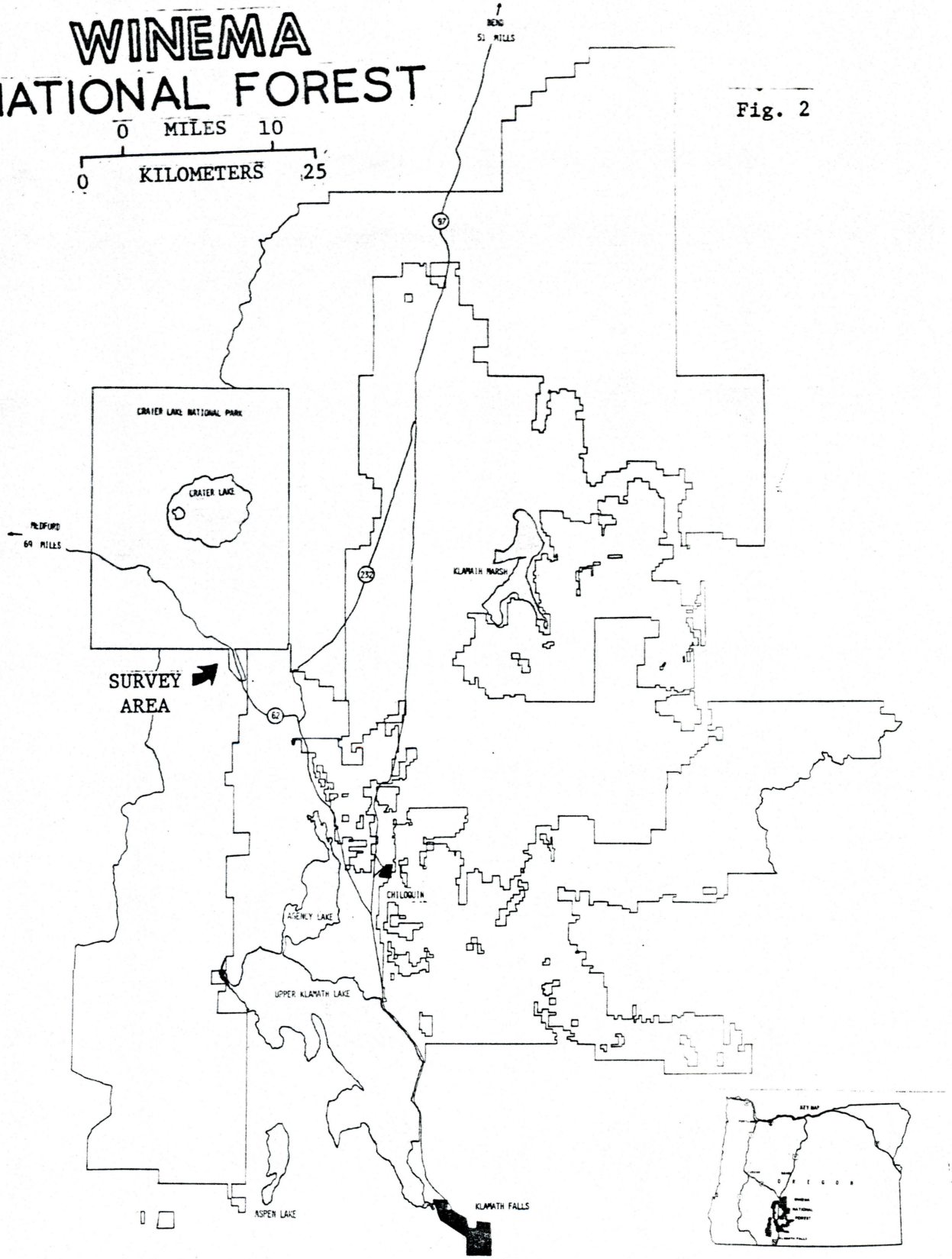
WINEMA
NATIONAL FOREST
0 MILES 10
0 KILOMETERS 25
BEND
51 MILES
CRATER LAKE NATIONAL PARK
CRATER LAKE
MEDFORD
69 MILES
SURVEY
AREA
KLAMATH MARSH
97
232
62
CHILOQUIN
AGENCY LAKE
UPPER KLAMATH LAKE
ASPEN LAKE
KLAMATH FALLS
OREGON

Fig. 2

is uneven-aged and composed of several conifer species. White fir [*Abies concolor* (Gord. and Glend.) Lindl.] is the dominant species in association with Shasta red fir (*Abies magnifica* Murr. var. *shastensis* Lemm.), ponderosa pine (*Pinus ponderosa*, Laws), and incense-cedar *Libocedrus decurrens*, Torr.). Lodgepole pine (*Pinus contorta*, Dougl.), western white pine (*Pinus monticola*, Dougl.), and sugar pine (*Pinus lambertiana*, Dougl.) are also present.

The area is Site Class IV (Site Index 100, base 100 years). Understory vegetation includes primarily *Carex pensylvanica* Lam., *Pyrola rotundifolia* L., and *Fragaria* spp., and brush species *Castanopsis chrysophylla* (Dougl.) A.DC., *Ceanothus velutinus* Dougl. ex Hook, and *Pachistima myrsinites* (Parsh) Raf.

Elevation averages 1525 m. Annual precipitation ranges from 75 to 89 cm. Mean January and July temperatures are -2° and 20° C, respectively. Soils are derived from olivine basalts and olivine-bearing basaltic andesites (Williams, 1942).

The survey area is managed by the Forest Service and was partially logged in 1930 through 1940 and again in 1965. Selection cuts of mostly old-growth ponderosa pine resulted in a gradual stand conversion to white fir.

Survey Methods

Approximately 230 hectares (574 acres) were systematically ground surveyed (July 1976) by employing 65 variable plots (BAF 30) and 65 fixed circular plots (.004 ha) spaced at 201-meter (10-chain) intervals (Figure 3). Plot centers were the same for both fixed and variable plots. All trees not tallied in variable plots were tallied if they fell within fixed plots, these trees generally being of smaller diameter. All trees within the plots were tallied regardless of species, merchantibility, or condition (alive, dead, standing, or down). The following data were recorded for each tree: (1) Tree species, (2) DBH (1.4 m above ground), (3) crown class, (4) age class, and (5) presence of root rot. Approximate boundaries of root rot infection in the survey area were sketched on a map as the survey was made.

Root rot examinations were made by excavating the soil around the root collar of each tree with a pulaski and removing a small section of bark to expose the cambium. Presence of characteristic white mycelial fans of fungus beneath the bark was a positive indicator of Armillaria root rot (Figure 4). Mycelial fans beneath the bark of trees which have been dead for some time deteriorate, but their remnants can often be seen after deeper soil excavation and bark removal.

All data were tabulated by computer using the standard Stand Examination System Version Four of the Forest Service, Region 6, Portland, Oregon; the same program used to analyze all stand exams from National Forests in Oregon and Washington.

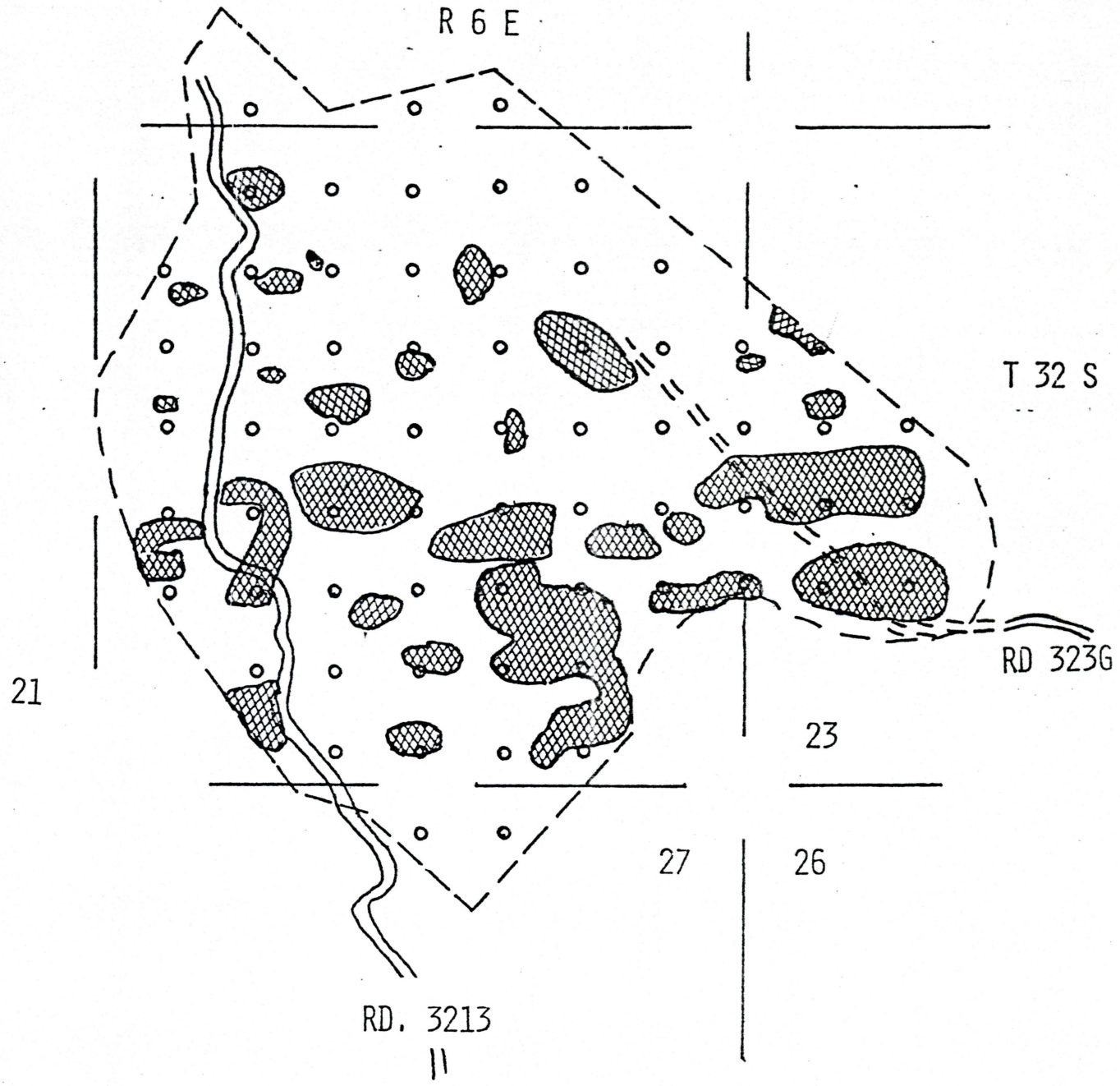

Figure 3.--Map of survey area showing approximate boundaries of the survey (dotted lines), area infected by Armillaria root rot (hatchmarks), and plot locations (circles). Plots are separated by 201 meters (10 chains).

Figure 4 -- Mycelial fans of *A. mellea* beneath the bark of a recently killed ponderosa pine.

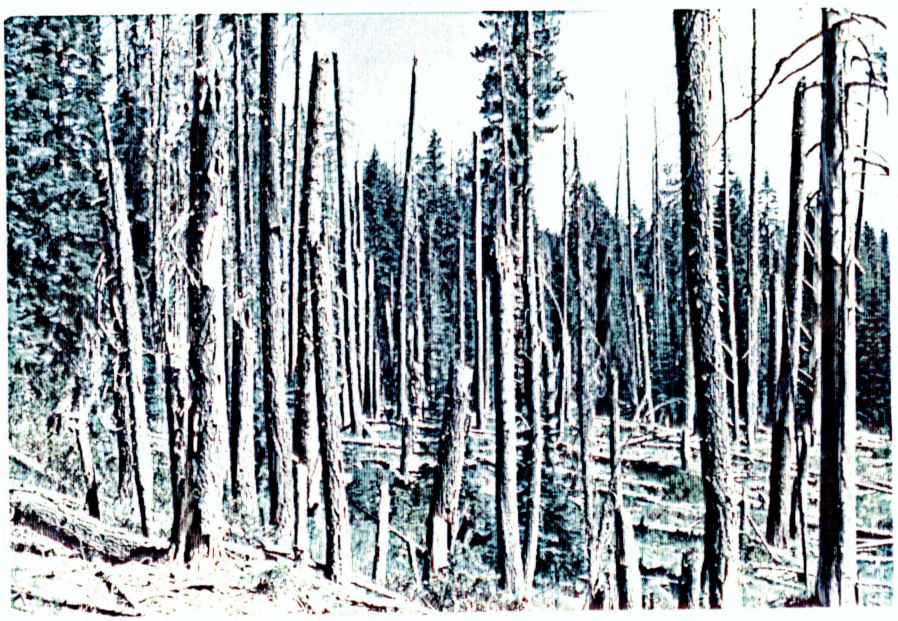

Figure 5 -- One of several disease centers created by *A. mellea* in a stand of old-growth white fir.

RESULTS

Of 65 plots, 41 (63 percent) have at least one Armillaria-infected tree (Figure 3). No other root disease was detected in the survey area. The area surveyed has an average of 2,161 trees/ha (875/acre) with a volume of 452 m^3/ha (27,695 bd. ft.[1/] or 6,464 $ft.^3$/acre) (Table 1). At least 7 percent of the stems have detectable Armillaria root rot but 34 percent of the board foot volume (32 percent of the cubic volume) is infected. More than half of the infected timber has been killed by the fungus, and the other half will probably die within 5 years. Timber mortality due to other causes is negligible. Most mortality is occurring in commercial sawtimber trees (27.8 to 53.1 cm or 11.0 to 20.9 in. DBH) (Table 2).

In the area surveyed, 80 percent of the total stems are white fir, 9 percent Shasta red fir and 5 percent incense-cedar. Although only 7 percent of the white fir stems have detectable root rot (Table 3), 38 percent of the cubic volume (43 percent bd. ft.) is infected (Table 4), indicating again that infection and mortality are occurring in the larger diameter classes.

Root rot incidence appears high (42 percent) in lodgepole pine and is absent in sugar pine, but only a relatively small number of stems were encountered, 1.0 and 0.2 percent, respectively. No root rot was detected in incense-cedar, a species of low commercial value.

1/Scribner Rule

Table 1.--Number of stems and volume of Armillaria infected timber for all species and size classes.

	Healthy		Armillaria Infected						Dead Other		Total
			Live		Dead		Total				
Stems											
per acre	808	(93%)	27	(3%)	39	(4%)	66	(7%)	1	(<1%)	875
per hectare	1,996		66		96		162		3		2,161
Board-feet[1/]											
per acre	18,006	(65%)	2,364	(9%)	7,049	(25%)	9,413	(34%)	276	(1%)	27,695
Cubic-feet											
per acre	4,329	(67%)	574	(9%)	1,500	(23%)	2,074	(32%)	62	(1%)	6,464
Cubic-meters											
per hectare	303	(67%)	40	(9%)	105	(23%)	145	(32%)	4	(1%)	452

1/Scribner rule

Table 2.--Number of Armillaria infected stems per unit area by diameter class for all species.

Diameter Class	Healthy		Armillaria Infected: Live		Dead		Total		Total
0.0-0.9 in	360.3[1/]	(>99%)	1.5	(1%)	0		1.5	(1%)	361.9
0.0-2.3 cm	889.8[2/]		3.7		0		3.7		893.5
1.0-4.9 in	260.3	(97%)	3.1	(1%)	6.2	(2%)	9.3	(3%)	269.6
2.4-12.4 cm	642.9		7.7		15.3		23.0		665.9
5.0-10.9 in	128.6	(85%)	12.5	(8%)	10.8	(7%)	23.3	(15%)	151.9
12.5-27.7 cm	317.6		30.9		26.7		57.6		375.2
11.0-20.9 in	46.3	(65%)	8.2	(11%)	17.1	(24%)	25.3	(35%)	71.6
27.8-53.1 cm	114.4		20.3		42.2		62.5		176.9
21 in +	12.8	(68%)	1.3	(7%)	4.7	(25%)	6.0	(32%)	18.8
53.2 cm +	31.6		3.2		11.7		14.9		46.5

1/Stems per acre
2/Stems per hectare

Table 3.--Number of Armillaria infected stems per unit area by species for all diameter classes.

Species	Healthy		Armillaria Infected: Live		Dead		Total		Total
White fir	651.9[1/]	(93%)	22.2	(3%)	28.7	(4%)	50.9	(7%)	702.8
Abies concolor	1,610.2[2/]		54.8		70.9		125.7		1,735.9
Shasta red fir	74.5	(91%)	0.9	(1%)	6.9	(8%)	7.8	(9%)	82.3
Abies magnifica var. *shastensis*	184.0		2.2		17.0		19.2		203.2
Incense cedar	43.6	(100%)	0		0		0		43.6
Libocedrus decurrens	107.7		0		0		0		107.7
Ponderosa pine	20.9	(82%)	1.3	(5%)	3.2	(13%)	4.5	(18%)	25.4
Pinus ponderosa	51.7		3.3		7.8		11.1		62.8
Western white pine	12.8	(99%)	0.1	(<1%)	0.1	(<1%)	0.2	(1%)	13.0
Pinus monticola	31.6		0.2		0.2		0.4		32.0
Lodgepole pine	2.9	(58%)	2.1	(42%)	0		2.1	(42%)	5.0
Pinus contorta	7.2		5.3		0		5.3		12.5
Sugar pine	1.6	(100%)	0		0		0		1.6
Pinus lambertiana	3.9		0		0		0		3.9

1/Stems per acre
2/Stems per hectare

Table olume of Armillaria infected timber per unit by species for all diameter classes.

Species	Healthy		Armillaria Infected: Live		Armillaria Infected: Dead		Armillaria Infected: Total		Total
White fir	9,020[1/]	(57%)	1,367	(9%)	5,377	(34%)	6,744	(43%)	15,764
Abies concolor	2,518[2/] 176[3/]	(62%)	369 26	(9%)	1,187 83	(29%)	1,556 109	(38%)	4,074 285
Shasta red fir	3,280	(88%)	294	(8%)	160	(4%)	454	(12%)	3,734
Abies magnifica var. *shastensis*	813 57	(87%)	62 4	(7%)	58 4	(6%)	120 8	(13%)	933 65
Incense-cedar	810	(100%)	0		0		0		810
Libocedrus decurrens	197 14	(100%)	0 0		0 0		0 0		197 14
Ponderosa pine	4,180	(70%)	406	(7%)	1,363	(23%)	1,769	(30%)	5,949
Pinus ponderosa	671 47	(68%)	75 5	(8%)	237 17	(24%)	312 22	(32%)	983 69
Western white pine	554	(67%)	125	(15%)	149	(18%)	274	(33%)	828
Pinus monticola	89 6	(72%)	17 1	(14%)	17 1	(14%)	34 2	(28%)	123 8
Lodgepole pine	65	(27%)	172	(73%)	0		172	(73%)	237
Pinus contorta	25 2	(32%)	51 4	(68%)	0 0		51 4	(68%)	76 6
Sugar pine	97	(100%)	0		0		0		97
Pinus lambertiana	17 1	(100%)	0 0		0 0		0 0		17 1

1/Board-feet per acre (Scribner)
2/Cubic-feet per acre
3/Cubic-meters per hectare

DISCUSSION

Disease Expression in the Stand

Armillaria root rot is characterized in the survey area by the presence of several large disease centers (1 to 4 ha, 2.5 to 10 ac) containing numerous stubs and snags predominantly of larger diameter class (Figure 5). Several healthy appearing but occasionally infected trees are found within and between adjacent disease centers. Although only 230 hectares (574 acres) were systematically surveyed, mortality caused by Armillaria root rot is present in at least 810 hectares (2,000 acres) of surrounding forest, generally at lower incidence than in the survey area.

Estimates of the number and wood volume of living infected trees in the survey area are conservative, since only trees with infections at the root collar were recorded. The majority of infected trees may have infections only on lateral or lower taproots, and these were not examined. In pole-sized ponderosa pine stands in southern Washington, Armillaria-infected root material was shown to extend as much as 6.7 m (22 feet) from the nearest dead tree (Shaw, 1974). Any tree within this zone, therefore, has the possibility of being infected. This zone also increases with increasing tree diameter. The fate of living trees with infections on lateral or lower taproots is speculative, but infection may proceed to the root collar resulting in tree mortality.

Infection and mortality in the survey area has been occurring for many decades as evidenced by the advanced stages of deterioration in many killed trees. Occasional old-growth stumps of trees harvested in previous years were noted in many disease centers in the survey area. It is possible that the origin of these disease centers is associated with past harvesting of healthy appearing but Armillaria-infected old-growth ponderosa pine, similar to the situation in southern Washington. Following tree harvesting, *A. mellea* from these infected pine stumps probably infected the predominantly white fir understory, and with time, the disease advanced through the maturing fir stand. The larger disease centers may therefore represent an infection process that has been occurring for over 40 years.

In summary, it may be speculated that severity of the disease within the area surveyed is associated with a combination of two factors: (1) Ideal environmental conditions (soil, host type, etc.) for fungus growth and survival, and (2) harvesting of infected old-growth pine resulting in an increase in fungal infection energy (inoculum potential).

Disease Management Considerations

Practical control measures for Armillaria root rot are currently under investigation in the Pacific Northwest. The most promising measure to date involves "push-out logging" of all visibly infected and highly susceptible trees in root rot-infected areas (Roth et al., 1977). Visibly infected and highly susceptible trees, those within a certain minimum distance[2/] from the nearest root rot-killed tree, are marked for cutting and then pushed over

2/Distance (feet) = 8.615 + 1.071 (DBH of killed tree, inches)

with a bulldozer. As a result, the majority of the root system is exposed and left on the soil surface. If the stem is merchantable, it is cut and removed. Since the root rot fungus can survive in moist stumps for decades even after tree death, stump excavation essentially destroys the fungus through desiccation and prevents spread to adjacent trees. Such treatment of entire infected areas minimizes future timber mortality due to root rot. A variation of root excavation by "push-out logging" is excavation of infected and highly susceptible stumps following conventional logging.

Costs of "push-out logging" in southern Washington ponderosa pine forests were estimated at $125 per hectare ($50 per acre) in level terrain where infection was moderate and scattered (Roth, personal communication). Effective treatment in areas of severe infection similar to the survey areas essentially result in small clearcuts with total stump excavation.

Planting of conifers less susceptible to Armillaria root rot as an alternative to stump removal is a risky measure. Most conifers in a natural state are somewhat susceptible to the pathogen, and their susceptibility in an artificial state, such as plantings, appears to increase (Buckland, 1953). Disease incidence also appears higher when non-native vs. native species are planted (Singh, 1975). Much of the present knowledge concerning the root rot susceptibility of various conifer species is speculative and is still under investigation.

Precommercial thinning of sapling ponderosa pine has been shown to reduce mortality due to Armillaria root rot when compared to unthinned stands in central Oregon (Johnson and Thompson, 1975). The effect of thinning other tree species or pines of larger diameter in Armillaria-infected stands for the purpose of disease control is being investigated. It is possible that commercial thinning of infected stands may increase the disease because of an increase in food base for the fungus. However, severe damage caused by Armillaria root rot is not common in commercially thinned stands throughout Oregon and Washington.

The use of chemical fumigants to eradicate *A. mellea* from infected ponderosa pine stumps as an alternative to stump removal shows promise as a possible control measure in special situations but is only in the experimental stages of development (Filip and Roth, 1977). Further testing is needed to determine the economic feasibility of stump fumigation on an operational basis in the forest.

Future timber management of the survey and surrounding areas warrants careful consideration. If the stand is left undisturbed, infection and mortality by *A. mellea* will continue in existing trees, as well as in trees which will become established. Existing disease centers may continue to expand and coalesce leaving large areas of dead and dying trees. It is possible, however, that the total land area affected will remain constant, as is the case in certain southern Washington pine forests (Shaw et al., 1976). While some disease centers continued expansion, others ceased unexplainably and became restocked with apparently healthy seedlings and saplings. Although total acreage of infected land remained constant over a 14-year period in southern Washington, total wood volume affected increased due to an increase in average stand diameter with time. Even though a balance between newly infected sites and reclaimed sites may be achieved with time, a certain portion will always remain out of production indefinitely.

Selective harvesting of merchantable dead and highly susceptible trees will prevent further decrease in commercial value through wood deterioration and utilize highly susceptible trees that may be infected and die. Such practice, however, will not prevent future infection and mortality in residual trees or regeneration. On the contrary, the harvesting of living, infected timber, especially of large diameter, could create new disease centers or intensify old centers because of the associated increase in inoculum potential.

The creation of new disease centers by harvesting infected, large diameter trees is certainly the exception rather than the rule. Several thousand acres of similar forest type throughout the Region have been selectively cut in the past without the creation of new centers. The exact conditions required to trigger epidemics of the ubiquitous fungus, *A. mellea* are still unknown.

Tree harvesting with stump removal is probably the most effective method of disease management in root rot-infected areas. Stump excavation will remove the inoculum source and should avoid creation of new infection centers or intensification of existing ones. In moderately to severely infected areas, stump excavation of all infected and highly susceptible trees following conventional logging or with "push-out logging" should minimize infection and mortality (1) in the surrounding stand, (2) in residual trees within the disease center, and (3) in either natural or artificial regeneration. Some infection and mortality, however, will probably continue where infected root material is missed. A practical solution is not complete eradication of root rot from the site, but rather a minimizing of future infection and mortality by removal of most of the fungus inoculum from the soil.

In summary, management alternatives in stands moderately to severely infested with Armillaria root rot in the survey and surrounding areas include:

1. Stump excavation of all infected and highly susceptible trees following conventional logging or by "push-out logging." Replanting of openings with desired species following stump excavation and slash disposal.

2. Selective harvesting of only merchantable dead and highly susceptible trees. Possible site preparation for natural regeneration (favor incense-cedar). No artificial planting.

3. Delineating areas of root rot infestation and essentially leaving these areas undisturbed.

Selection of a particular treatment or combination of treatments should be based on an analysis of site productivity, cost/benefit ratio, long-range management plans for the area, and environmental impact.

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REFERENCES

Buckland, D. C.
1953. Observation on *Armillaria mellea* in immature Douglas-fir. For. Chron. 29:344-347.

Childs, T. W. and Shea, K. R.
1967. Annual losses from disease in Pacific Northwest forests. USDA Forest Service Research Paper PNW-20, PNW Forest and Range Experiment Station, Portland, Oregon. 19 pp.

Filip, G. M. and Roth, L. F.
1977. Stump injection of soil fumigants to eradicate *Armillariella mellea* from young-growth ponderosa pine killed by root rot. Can. J. For. Res. (In press).

Johnson, D. W.
1976. Incidence of diseases in National Forest plantations in the Pacific Northwest. Plant Dis. Reptr. 60:883-885.

Johnson, D. W. and Thompson, J. H.
1975. Effect of precommercial thinning on ponderosa pine, *Pinus ponderosa*, infected with *Armillaria mellea*. Plant Dis. Reptr. 59:308-309.

Raabe, R. D.
1962. Host list of the root rot fungus, *Armillaria mellea*. Hilgardia. 33:25-88.

Rishbeth, J.
1972. The production of rhizomorphs by *Armillaria mellea* from stumps. Eur. J. For. Path. 2:193-205.

Roth, L. F., Shaw, C. G. III, and Rolph L.
1977. Marking ponderosa pine to combine commercial thinning and control of Armillaria root rot. J. of For. (In press).

Shaw, C. G. III
1974. Epidemiological insights into *Armillaria mellea* root rot in a managed ponderosa pine forest. Unpublished Doctoral Dissertation, Corvallis, Oregon State University. 201 pp.

Shaw, C. G. III, Roth, L. F., Rolph, L., and Hunt, J.
1976. Dynamics of pine and pathogen as they relate to damage in a forest attacked by Armillaria. Plant Dis. Reptr. 60:214-218.

Singh, P.
1975. *Armillaria* root rot: Distribution and severity in softwood plantations in Newfoundland. Acta Phytopathologica Academiae Scientiarum Hungaricae. 10:389-406.

Williams, H.
1942. The geology of Crater Lake National Park. Carnegie Institute of Washington Publication 540, Washington, D.C. 162 pp.